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What is This?
Rotational and Translational Stability of Different Methods for Direct Acromioclavicular Ligament Repair in Anatomic Acromioclavicular Joint Reconstruction

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Background: Many reconstructions of acromioclavicular (AC) joint dislocations have focused on the coracoclavicular (CC) ligaments and neglected the functional contribution of the AC ligaments and the deltotrapezial fascia.

Purpose: To compare the modifications of previously published methods for direct AC reconstruction in addition to a CC reconstruction. The hypothesis was that there would be significant differences within the variations of surgical reconstructions.

Study Design: Controlled laboratory study.

Methods: A total of 24 cadaveric shoulders were tested with a servohydraulic testing system. Two digitizing cameras evaluated the 3-dimensional movement. All reconstructions were based on a CC reconstruction using 2 clavicle tunnels and a tendon graft. The following techniques were used to reconstruct the AC ligaments: a graft was shuttled underneath the AC joint back from anterior and again sutured to the acromial side of the joint (group 1), a graft was fixed intramedullary in the acromion and distal clavicle (group 2), a graft was passed over the acromion and into an acromial tunnel (group 3), and a FiberTape was fixed in a cruciate configuration (group 4). Anterior, posterior, and superior translation, as well as anterior and posterior rotation, were tested.

Results: Group 1 showed significantly less posterior translation compared with the 3 other groups (P < .05) but did not show significant differences compared with the native joint. Groups 3 and 4 demonstrated significantly more posterior translation than the native joint. Group 1 showed significantly less anterior translation compared with groups 2 and 3. Group 3 demonstrated significantly more anterior translation than the native joint. Group 1 demonstrated significantly less superior translation compared with the other groups and with the native joint. The AC joint of group 1 was pulled apart less compared with all other reconstructions. Only group 1 reproduced the native joint for the anterior rotation at the posterior marker. Group 4 showed significantly increased distances for all 3 measure points when the clavicle was rotated posteriorly.

Conclusion: Reconstruction of the AC ligament by direct wrapping and suturing of the remaining graft around the AC joint (group 1) was the most stable method and was the only one to show anterior rotation comparable with the native joint. In contrast, the transacromial technique (group 3) showed the most translation and rotation.

Clinical Relevance: An anatomic repair should address both the CC ligaments and the AC ligaments to control the optimal physiologic function (translation and rotation).

Keywords: acromioclavicular (AC) joint; AC joint dislocation; anatomic acromioclavicular joint reconstruction; AC separation; coracoclavicular ligament reconstruction

The treatment of dislocations of the acromioclavicular (AC) joint remains a subject of debate because of the lack of consensus regarding the optimal management. Current reviews have identified >150 different surgical techniques for surgical treatment of AC joint dislocations.1,18 The clavicle is the anterior strut to the scapula, and the proper function of the AC and coracoclavicular (CC) ligaments contributes to the physiologic motion of the scapula. The capsuloligamentous structures of the AC joint not only
control horizontal and vertical translation of the distal clavicle but also play an important role in controlling rotation. Ludewig et al12 showed the importance of this rotational motion as a relevant factor for forward elevation of the arm, particularly at higher degrees and to allow physiologic scapulothoracic function. Shortening of the clavicle or instability of the AC joint may position the scapula in a protracted and internally rotated position.9,13 Therefore, injury to the AC joint not only affects the glenohumeral function but also may have a negative effect on scapulothoracic function and scapulohumeral rhythm.

Recent biomechanical and clinical studies have demonstrated advantages to an anatomic reconstruction of the CC ligaments when stabilizing the dislocated AC joint.2,4,14,15,20,22 Many of these procedures have focused on the CC ligaments (conoid and trapezoid ligaments) and have neglected the functional contribution of the AC ligaments and the deltrotrapezial fascia.5,20,22 In our experience, and according to previous literature, an anatomic repair should address both the CC ligaments and the AC ligaments to restore the optimal physiologic function. Biomechanical data evaluating direct AC joint reconstructions are still lacking. Grutter and Petersen8 evaluated the load to failure of a modified Weaver-Dunn procedure, an anatomic AC reconstruction using a palmaris longus graft, and an anatomic AC reconstruction using a flexor carpi radialis graft.10 In their technique, they passed the graft through a tunnel in the acromion to reconstruct the AC ligaments after an anatomic reconstruction of the CC ligaments. Michlitsch et al16 and Gonzales-Lomas et al17 both developed an intramedullary technique using a graft to reconstruct the AC ligaments. Most of these reconstructions were biomechanically compared with nonanatomic reconstructions such as the Weaver-Dunn procedure. Up to now, no biomechanical studies have directly compared these AC ligament reconstruction techniques with each other in conjunction with a standardized CC repair. In addition, nearly all of the current biomechanical studies have focused on the evaluation of failure under unidirectional loading and neglected the 3-dimensional (3D) function of the joint, including rotational analysis.

The purpose of the present study was to evaluate and directly compare the biomechanical performance of the previously published methods for direct AC ligament reconstruction in addition to anatomic CC reconstructions for horizontal and vertical translation as well as anterior and posterior rotation. The hypothesis was that there would be significant differences within the variations of surgical reconstructions when tested against each other and compared with the native joint.

MATERIALS AND METHODS

Specimen and Preparation

Twenty-four fresh-frozen cadaveric shoulders were used in this study. Specimen preparation was done in accordance with previously published methods.2,3 Before the day of testing, each specimen was thawed overnight at room temperature. Specimens were disarticulated at the glenohumeral joint, and the clavicle and scapula were dissected free of all soft tissue except the AC ligaments, CC ligaments, and coracoacromial ligament. All specimens then underwent bone density evaluation with a dual-energy x-ray absorptiometric scan (Lunar DPX IQ; GE Healthcare). The scapula was then potted using plaster of Paris. The scapula was trimmed such that, when potted in a 7.6 cm (diameter) × 7.6 cm (length) section of polyvinyl chloride (PVC) pipe, the glenoid face was parallel to the floor when the PVC pipe was standing upright. This enabled scapular fixation to a swivel fixture on the X-Y table of a servohydraulic testing system (MTS Systems Corp). The clavicle was potted with bone cement in a 3.2 cm (diameter) × 6.4 cm (length) section of PVC pipe such that its long axis was centered and ran parallel within the PVC pipe. This enabled clavicular fixation to the actuator of the MTS machine with a custom aluminum clamp.

An optical measuring system using 2 digitizing cameras was used to evaluate the 3D movement of the specimen (anterior, posterior, and superior translation as well as axial and longitudinal rotation). Pins with white markers were inserted into anatomic regions of the scapula and clavicle. Markers were labeled (1-10) and placed on the following structures: (1) lateral coracoid, (2) medial coracoid, (3) anterior proximal clavicle, (4) anterior distal clavicle, (5) superior distal clavicle, (6) posterior distal clavicle, (7) anterior acromion, (8) superior acromion, (9) posterior acromion, and (10) scapular spine. Two cameras were set up to track the movement of these markers during all trials for 3D video motion analysis by using MaxTraq 3D (Innovation Systems Inc) software. Camera 1 captured the anterior-posterior view. Camera 2 was placed 90° to camera 1 and captured the axial view. Calibration was done before testing each specimen by using a calibration frame and the MaxTraq system to obtain 3D coordinates. This created a 3D window into which each specimen was placed for testing.

The 3 marker positions to determine the distraction of the AC joint (the change in distance between the clavicle and acromion) under clavicle rotation were the anterior AC ligament, superior AC ligament, and posterior AC ligament. For translation measurements, the MTS data were chosen as the main outcome variable. This allowed
comparsion of the data with previous studies and consistent with previous methods. MaxTraq data were chosen as the primary outcome variable for distraction of the AC joint under rotational stress because this was thought to best represent the actual changes. In addition, photographs and x-ray video (using a mini C-arm [OEC Mini-View 6800; GE Medical Systems Inc]) were taken of each trial to note anatomy and ligament status (Figure 1).

Surgical Reconstruction Techniques

The native joint with intact AC and CC ligaments served as the control group and was tested according to the biomechanical protocol. After evaluation of the native joint, both the AC and CC ligaments were cut, and reconstruction was performed according to 1 of the following 4 techniques.

Group 1 (anatomic CC ligament reconstruction [ACCR]). The AC and CC ligaments were reconstructed using a technique modified from a previously published surgical technique (ACCR). A semitendinosus fresh-frozen tendon (5 mm) was used as the biological graft and whip stitched with No. 2 FiberWire sutures (Arthrex Inc) in a baseball-type fashion at both distal 2 tails of the graft (2-2.5 cm). For the CC reconstruction, a 5-mm central bone tunnel was created at the base of the coracoid. The graft was then shuttled through this tunnel and looped back over the medial side of the coracoid. Then the AC joint was anatomically repositioned, and bone tunnels in the distal clavicle were created. First the tunnel for the conoid ligament was created approximately 45 mm medial from the distal end of the clavicle in the posterior half of the clavicle in a superior-to-inferior direction (5-mm reamer). The second 5-mm tunnel for the trapezoid ligament was placed approximately 25 mm from the lateral edge of the distal clavicle. Both limps of the graft were then shuttled through the tunnels to reconstruct the physiologic CC ligaments (conoid = proximal end, trapezoid = distal end). The limb exiting the conoid tunnel was fixed first using a 5.5 × 8 mm polyetheretherketone interference screw (Arthrex Inc). The other limb of the graft exiting the trapezoid tunnel is cyclically tensioned to remove all slack out of the system, and a similarly sized screw is subsequently placed into the trapezoid ligament tunnel to fix this end of the graft. The graft was positioned in a way that the long end of the remaining graft exited the trapezoid tunnel and only a short end exited the conoid tunnel. This allowed enough remaining graft to further reconstruct the AC ligaments.

For reconstruction of the AC ligaments in the ACCR technique, the graft was looped over the top of the AC joint to reinforce this repair. High-strength nonabsorbable sutures were used to suture it into the most posterior tissue on the acromial side of the joint. Then the remaining graft was shuttled underneath the AC joint back from anterior and again sutured to the acromial side of the joint and itself. Finally, the superior AC capsule was sutured (Figure 2).

Group 2 (intramedullary). After cutting the AC and CC ligaments, an identical technique as described for group 1 was used to restore the CC ligaments. The reconstruction of the AC ligaments was then performed in a modification of the technique presented by Gonzales-Lomas et al. Two 5-mm socket tunnels were created in the intra-articular ends of the distal clavicle and the acromion (1.5 cm in length) without performing a distal clavicle excision. Next, 1-mm drill holes were placed through the superior cortex of the acromion and clavicle, 1.5 cm from their respective articular margins, connecting with the socket tunnels.

The remaining graft exiting the trapezoid tunnel was then cut and prepared to a size of 3 cm (length) and 5 mm (width) and was finally augmented at both ends with No. 2 FiberWire sutures. The free ends of the sutures were passed into the distal clavicle and acromion tunnels and out the superior drill holes. Tension on the ends of the sutures pulled the graft into the intramedullary tunnels. Both ends of the sutures were then passed through a 3.5-mm suture button (Arthrex Inc) at each end and tied to the clavicular and acromial sides, respectively (Figure 2).

Group 3 (transacromial). After cutting the AC and CC ligaments, an identical technique as described for group 1 was used to restore the CC ligaments. The AC ligament was reconstructed in a new technique modified from the technique previously described by Gutter and Petersen. For this, 1 hole was drilled from lateral to medial in the acromion, aiming at the midline of the clavicle and exiting about 1.5 cm lateral to the medial acromion edge (5 mm). Then the limb exiting the trapezoid tunnel was pulled through the created tunnel and passed back over the acromion. Finally, both limbs were sutured with No. 2 sutures (Figure 2).

Group 4 (8-turn). The reconstruction of the CC ligaments was also performed in an identical fashion as described for group 1 after cutting all ligamentous structures. The AC ligament was then reconstructed with the use of a FiberTape according to a technique published by Michlitsch et al. Tunnels were created in the distal...
clavicle (1 cm medial to lateral edge) and the acromion (1 cm lateral to acromion border). A FiberTape was passed through the tunnels in a cruciate, single-strand, single-knot configuration. Sutures were then knotted on top of the clavicle (Figure 2).

Biomechanical Testing Protocol

To completely evaluate the complex 3D function of the AC joint and the contribution of the repaired constructs, each reconstructed specimen underwent both translational and rotational testing. Translational testing included anterior, posterior, and superior displacements of the clavicle with respect to the acromion. Rotational testing included evaluation of AC joint distraction under anterior and posterior rotation of the clavicle about its long axis. Continuous measurement of displacements in all directions, video analysis, photographs, and x-ray video were taken during all trials.

Translational Testing. For translational testing, a 70-N load was used on the basis of its use in other studies.\(^2,3,15\) The clavicle was fixed to the actuator, and the scapula was fixed to a swivel fixture on the X-Y table. The actuator applied loads to the clavicle, and the direction of translation was recorded as movement of the clavicle with respect to the acromion. For anterior-posterior testing, the specimens were fixed into the MTS machine such that the long axis of the potted clavicle was perpendicular to the actuator, and anterior displacement of the clavicle with respect to the acromion was in line with superior pull of the actuator. The actuator was adjusted so that anatomic relation between the acromion and clavicle could be achieved by palpation. Once anatomic positioning was achieved, the clavicle was rigidly clamped. The MTS machine was zeroed, and the position of the X-Y table was taken using MicroScribe (Solution Technologies, Inc). This was designated as the initial neutral position. Next, the specimen was loaded anterior to 70 N, with displacement of the clavicle and the new position of the X-Y table again recorded. The specimen was then brought back to neutral and the position of the X-Y table compared with the initial neutral position.

Superior displacement was then evaluated. The specimens were oriented in the MTS machine such that the long axis of the clavicle was perpendicular to the actuator and superior displacement of the clavicle with respect to the acromion was in line with superior pull of the actuator. The scapula was first rigidly fixed to the X-Y table such that the plane of the glenoid face was perpendicular to the floor, while the clavicle was fixed to the actuator in a nonrigid fashion. The actuator was adjusted so that anatomic relation between the acromion and clavicle could be achieved by palpation. Once anatomic positioning was achieved, the clavicle was rigidly clamped. The MTS machine was zeroed, and the position of the X-Y table was taken using MicroScribe. This was designated as the initial neutral position. Next, the specimen was loaded superiorly to 70 N, with displacement recorded by the MTS machine. The new position of the X-Y table was recorded to measure movement of the scapula. The specimen was then brought back to neutral and the position of the X-Y table compared with the initial neutral position.

Rotational Testing. Angular control was used for rotational testing using a methodology closely adapted to the methods described by Kippe et al.\(^11\) The main difference

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**Figure 2.** Demonstrating the 4 groups of reconstruction of the acromioclavicular ligaments on the basis of a standard reconstruction of the coracoclavicular ligaments: (A) group 1 (anatomic CC ligament reconstruction), (B) group 2 (intramedullary), (C) group 3 (transacromial), and (D) group 4 (8-turn).
was that an X-Y table was used to represent a “floating shoulder” just as in real-life scapular motion (restricted in the z-direction). The clavicle was rotated about its long axis 30° posterior and 20° anterior at a rate of 5° per second, as was done in a previous study. For each trial, the MTS machine recorded the axial torque and force applied to the clavicle. Anterior rotation was designated as the superior aspect of the clavicle moving anteriorly, and posterior rotation was designated as posterior movement of the superior aspect of the clavicle. For rotational testing, the attachment of the actuator was changed so that the potted clavicle could be fixed with its long axis in line with the shaft of the actuator. The scapula was first rigidly fixed to the X-Y table such that the plane of the glenoid face was parallel to the floor, while the clavicle was fixed to the actuator in a nonrigid fashion. The specimen was adjusted so that anatomic relation between the acromion and clavicle could be achieved by palpation. Once anatomic relation was achieved, the clavicle was rigidly clamped. The MTS machine was zeroed, and the position of the X-Y table was then taken using MicroScribe. This was designated as the initial neutral position. The specimen was then brought back to neutral and the position of the X-Y table recorded to serve as the neutral position for anterior testing. Anterior testing was then conducted, with the position of the X-Y table being taken at 20° and again once the specimen was brought back to neutral to compare with the initial neutral position. Next, the specimens underwent anterior-posterior cyclic loading over the designated 50° range. The first 3 cycles were used for preconditioning, and the fourth cycle was used for analysis. For the analysis cycle, torque and axial force required to rotate the clavicle over the desired range were recorded for both anterior and posterior directions. MaxTraq data were chosen as the primary outcome variable for distraction of the AC joint under rotational stress. For this, 3 marker distances (anterior, superior, and posterior) were chosen for determination of the distraction of the AC joint under rotation of the clavicles.

Statistical Analysis
The data were analyzed for variance if significant differences were found followed by Bonferroni post hoc analysis. An alpha level of .05 was set for all tests for the determination of significance. A power analysis (alpha value of .05 and power of 0.80) on the basis of a previous study was performed and revealed a minimum of 5 specimens per group for testing.

RESULTS
Specimens
The mean age of the included specimens was 68.8 ± 8.1 years. The overall bone density was 0.36 ± 0.13 g/cm². There was no statistical difference in bone mineral density when comparing the groups with each other (P = .576). The detailed information according to groups is given in

Figure 3. Box plot demonstrating the posterior translation under a 70-N load according to group and compared with the native joint. Circle indicates outlier. ACCR, anatomic coracoclavicular ligament reconstruction.

Appendix Table A1 (available in the online version of this article at http://ajsm.sagepub.com/supplemental).

Posterior Translation
Group 1 showed significantly less posterior translation compared with all 3 other reconstruction methods (group 2, P = .008; group 3, P = .001; group 4, P < .001) but no significant difference compared with the native joint. Groups 3 and 4 demonstrated significantly more translation than did the native joint (P = .006 and P < .001, respectively). Detailed data are shown in Figure 3 and Appendix Table A2 (available online).

Anterior Translation
Group 1 showed significantly less anterior translation compared with group 2 (intramedullary; P = .026) and group 3 (transacromial; P < .001). Group 3 also demonstrated more translation than did the native joint (P = .006 and P < .001, respectively). Detailed data are presented in Appendix Table A2 and Figure 4.

Superior Translation
Group 1 translated significantly less superiorly compared with all other groups and the native joint (P < .001). Native superior translation was significantly more compared with group 1 but was less compared with all other groups (P < .001). Detailed data are presented in Figure 5 and Appendix Table A2.

Anterior Rotation (20°)
Group 1 (ACCR) showed a significant increase for the anterior and superior marker position (P < .001) but not for the
posterior marker compared with the native joint \((P = .076)\). Distance for the superior marker was significantly less in group 1 (ACCR) compared with group 3 (transacromial) \((P = .03)\) and group 4 (8-turn) \((P = .002)\), whereas the distance for the posterior marker was significantly less compared with all other groups \((P = .002; P = .016; P < .001)\) and did not differ significantly compared with the native \((P = .076)\). Group 2 (intramedullary) showed significantly increased distances for all markers compared with the native \((P < .001)\) and for the posterior marker compared with group 1 (ACCR) \((P = .002)\). Distances of all markers significantly increased for group 3 (transacromial) compared with the native joint \((P < .001, P < .001, P = .032)\). Superior marker distance was significantly greater than in group 1 (ACCR; \(P = .024\)). Detailed data are shown in Figure 7 and Appendix Table A3.

**Posterior Rotation \((30^\circ)\)**

Distances for the anterior and superior markers were significantly increased when comparing group 2 (intramedullary) with the native joint \((P < .001)\) and with group 1 (ACCR) \((P = .009 \text{ and } P = .003, \text{ respectively})\). Group 3 (transacromial) demonstrated increased distances for the anterior and superior markers compared with the native joint \((P < .001)\) and for the superior \((P = .002)\) and posterior markers \((P < .001)\) as compared with group 1 (ACCR). Detailed data are shown in Figure 6 and Appendix Table A3 (available online).

**DISCUSSION**

The most important finding of the present study was that different methods of direct AC ligament reconstruction, in combination with a standardized anatomic reconstruction of the CC ligaments, demonstrated significant differences in control of clavicle translation and rotation.

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**Figure 4.** Box plot demonstrating the anterior translation under a 70-N load according to group and compared with the native joint. Asterisk indicates outlier. ACCR, anatomic coracoclavicular ligament reconstruction.

**Figure 5.** Box plot demonstrating the superior translation under a 70-N load according to group and compared with the native joint. Circles and asterisks indicate outliers. ACCR, anatomic coracoclavicular ligament reconstruction.

**Figure 6.** Box plot demonstrating the distances for the acromioclavicular joint markers under anterior rotation according to group and compared with the native joint. Circles indicate outliers. ACCR, anatomic coracoclavicular ligament reconstruction.
Reconstruction of the AC ligament by direct wrapping and suturing of the remaining graft around the AC joint (group 1) was the most stable method. In contrast, the transacromial technique (group 3) showed the most translation and distraction under rotational load.

Debski et al.6 showed in 2001 that when the AC ligaments were transected, the CC ligaments endured a 2-fold increase in load measured with horizontal load testing. However, currently no consensus exists on which technique should be added to a CC reconstruction to best stabilize the joint and allow physiologic motion. All 4 types of surgical techniques for AC ligament reconstruction evaluated in the present study were based on previously published studies, and nearly all of them were shown to be superior to a Weaver-Dunn reconstruction.5,8,15,16 However, on the basis of our literature review, no study exists evaluating these reconstructions in direct comparison with each other with the same biomechanical testing protocol. The present study is also the first to combine rotational, horizontal, and vertical translation testing. We compared 4 variations of direct AC ligament reconstructions when added to an anatomic CC ligament reconstruction. This allows a precise comparison of these individual techniques to enable surgeons to decide which technique can be best used in combination with a standardized CC reconstruction.

The wrapping of the residual graft around the AC joint (group 1) for reconstruction of the AC ligaments showed the least translation in all directions (anterior, posterior, and superior). This reconstruction also displayed results that closely resembled the native intact joint. We believe that wrapping the graft limb around the joint (group 1) best re-creates the anterior, superior, and posterior ligamentous structure of the AC capsule and therefore creates the most stable situation. The intramedullary technique (group 2) and the 8-turn suture (group 4) both showed less translation compared with the transacromial technique (group 3). Michliitsch et al.16 demonstrated significantly less superior-inferior translation of a comparable intramedullary technique compared with a Weaver-Dunn procedure. When comparing their technique with the native joint, no significant differences were shown. Gonzales-Lomas et al.,7 from the same group, evaluated an intramedullary AC and CC reconstruction compared with an isolated CC reconstruction (conoid and trapezoid ligament) and found significantly improved measures for anterior, posterior, and superior-inferior translation. Horizontal and vertical translations were decreased compared with the isolated CC reconstruction.

In our opinion, the results of the transacromial technique (group 3) show minor biomechanical stability because of the increased distance of the fixation points. This may allow increased motion of the ligament and a washer effect. Grutter and Petersens8 biomechanically evaluated such a technique and demonstrated increased stability of the anatomic reconstruction of the AC and the CC ligaments with a flexor carpi radialis graft (transacromial) compared with a Weaver-Dunn procedure. The surgical technique used in our study was a modification of this technique. However, we believe that the biomechanical properties should be comparable.

Nearly all of the previous known biomechanical studies that evaluated the properties of different repairs for AC joint instability measured only unilateral translation (vertical and horizontal) and load to failure. Because the complex 3D motion of the scapulohumeral joint is directly correlated with the optimal function of the AC joint (AC and CC ligaments), we believe that the stability of AC joint reconstructions should be defined not only in translational but also in rotational motion of the clavicle. Shortening of the clavicle or instability of the AC joint may position the scapula in a protracted and internally rotated position.9,16 It is also known from previous studies that scapular dyskinesis resulting from such a position may lead to glenohumeral and lateral shoulder pain as well as motion deficits.10

An anatomic method for reconstruction of the AC joint should allow normal amounts of rotation but at the same time provide stability to the repaired construct. The clavicle rotates about 40° to 50°, when the arm is elevated. Recent studies have described that the clavicle rotates roughly 30° compared with the thorax and about 20° compared with the scapula when the arm is elevated.12,19,21 In addition, Okiet al.17 demonstrated the importance of the CC and AC ligaments for scapular dyskinesis in their controlled laboratory study. In summary, physiologic AC joint function is necessary for the clavicle to play a major role in guiding scapulohumeral motion by serving as the anterior strut to the scapula.

Comparing our results for rotational analysis with the previous literature is difficult because this is the first study to use such a methodology. The idea was to demonstrate how far the reconstructed AC joint gets pulled apart under rotational stress. Overall, the AC joint of group 1 (ACCR) was less pulled apart compared with all other reconstructions. A reason for this finding may be that wrapping the tendon around the joint may help reconstruct all 3
important structures of the AC capsule (anterior, superior, and posterior ligaments). However, all reconstructions failed to reproduce the anterior rotation of the native joint for all measurements except for group 1 (ACCR) at the posterior marker. Group 4 (8-turn) was the only reconstruction that showed significantly increased distances for all 3 measure points when the clavicle was rotated posteriorly.

There are limitations to any biomechanical study. The in vitro nature of biomechanical evaluation can be a limiting factor in the application of the findings to the in vivo conditions of the shoulder complex. This is particularly true in the AC joint, with its specific 3D forces and complex contributions to multiple shoulder motions. Accurate replication of these forces in a cadaveric study may be difficult. Additionally, the mean age of the specimens was >65 years. However, the bone mineral density of each cadaveric specimen was measured to ensure that the specimens’ bone density was within physiologic ranges. Specimens were randomly assigned to the 4 groups. We performed statistical testing on all native specimens of all groups to check for any differences within these native groups. For this testing, 8 of 9 variables demonstrated no significant differences. The analysis of variance showed a significant difference only for the anterior translation. Therefore, we chose to present the results of this study that way for better replicability. However, the difference in anterior translation must be regarded when interpreting these results. We could not measure direct joint pressure or friction inside the AC joint because of economic reasons but used a native control, which enabled us to compare the biomechanical behavior of the reconstruction with the native joint stability. To evaluate changes in the biomechanical behavior of the tested reconstructions under rotational stresses, we used a new methodology based on previous descriptions. However, comparing the results with the previous literature was difficult because a very limited number of studies currently exist that investigated these rotational stresses. Additionally, biomechanical testing with cadaveric specimens does not allow the effects of biological healing to be measured, and therefore, we are able to draw conclusions only for the primary stability of the joint at a time point immediately after surgical reconstruction.

CONCLUSION

Different methods of direct reconstructions of the AC ligaments, in combination with a standardized anatomic reconstruction of the CC ligaments, demonstrated significant differences in control of clavicle translation and rotation. Reconstruction of the AC ligament by direct wrapping and suturing of the remaining graft around the AC joint (group 1) was the most stable method. In contrast, the transacromial technique (group 3) showed the most translation and distraction under rotational loads.

REFERENCES